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*Fifth Quarterly Progress Report*

# **Investigation of Liquid Metal Boiling Heat Transfer**

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THE UNIVERSITY OF MICHIGAN  
COLLEGE OF ENGINEERING  
Department of Chemical and Metallurgical Engineering  
Department of Mechanical Engineering

Fifth Quarterly Progress Report

INVESTIGATION OF LIQUID METAL  
BOILING HEAT TRANSFER

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under contract with:

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May 1963

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## FOREWORD

This report summarizes efforts to date on Phase II of Air Force Contract AF 33(616)-8277. A literature survey of liquid metal boiling technology has been released as an ASD report (ASD Tech. Rept. 61-594). Phase II consists of analytical and experimental studies with boiling metal systems. The investigation is being conducted at The University of Michigan in the Liquid Metals Laboratory of the Departments of Chemical and Metallurgical Engineering and in the Heat Transfer and Thermodynamics Laboratory of the Department of Mechanical Engineering. Professors Balzhiser, Hucke, Katz, and Tek of the Chemical Engineering faculty and Professors Clark and Merte of Mechanical Engineering are participating in the program. Misterns Barry, Colver, Padilla, and Smith, all graduate students in the College of Engineering, have responsibilities for specific segments of the study.

Mr. Lloyd Hedgepeth and Mr. Kenneth Hopkins are serving as project engineers for ASD.

Comments are solicited by both the authors and ASD.

## SUMMARY

Pool boiling data has been obtained for potassium from the outside of a 7/8-in diameter bayonet tube. Boiling curves were determined at pressures up to 45 psia and burnout measurements were taken for pressures up to 20 psia. The burnout flux at 1 atm. was 610,000 Btu/(hr)(sq ft) and showed less pressure dependence than predicted by the relationships of Noyes,<sup>(1)</sup> Zuber-Tribus,<sup>(2)</sup> and Kutateladze.<sup>(4)</sup>

Operation of the film boiler has been delayed by leaks in the environmental chamber surrounding the boiling system. Edge effects cannot be evaluated in the apparatus because of the 400°F limitation on the columbium when operating with water. The condenser, which dissipates heat by radiation, is flooded at these lower temperatures.

Startup difficulties with the loop have persisted and attempts to eliminate a plugging problem in the pump restriction are continuing. Prior to plugging, the loop and associated instrumentation was all functioning normally.

Agravic boiling with mercury will commence this summer as soon as assembly of the boiler is completed. Accelerations up to 20 g's will be obtained.

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## INTRODUCTION

Efforts during the last quarter have been devoted exclusively to operational problems with the exception of the agravic study which at the present time is in the final stages of assembly. Startup difficulties have been incurred in several of the phases and have resulted in a postponement of the final reporting date to September 30, 1963. It is expected that the high flux pool boiling and the film boiling studies will be completed prior to this date. However, the forced circulation studies and the agravic pool boiling studies are certain to extend through the summer months.

A substantial amount of data has been obtained with potassium on the high flux nucleate pool boiler. The apparatus has been operated with three boiling tubes to yield burnout data at pressures up to 20-lb/sq in, and boiling curves for pressures up to 45-lb/sq in. The data taking portion of this phase of the program is essentially complete and laboratory personnel are in the process of reducing and analyzing the data. A preliminary report of the findings is included in this report.

The film boiling program has encountered unanticipated delays arising from inadequate atmosphere control in the outer vessel surrounding the boiling tube. Leakage in the sealing glands resulted in the contamination of the inert gas atmosphere and catastrophic oxidation of the tantalum radiation heater. No damage, however, was done to the columbium boiling tube. These problems have proven more serious than originally anticipated and have required considerable attention during the past two months.

The preliminary runs with water to evaluate edge effects were performed as planned using resistance heaters and with no environmental chamber. It was necessary to keep the maximum temperature in the

boiler below 400°F while in contact with water and the atmosphere. This restriction prevented the achievement of stable film boiling in the upper chamber. As soon as the necessary modifications have been completed on the environmental chamber and the tantalum radiation heater has been replaced, the system will be charged with potassium in the upper chamber and sodium in the lower chamber. Operation will then commence as outlined in earlier reports. Data should be available by mid-July.

The forced circulation apparatus has been operated during the past quarter, but difficulties with plugging have persisted to date. Immediately following startup, circulation appeared normal with all components functioning properly. Apparently an accumulation of oxide in the restriction of the pump caused a decrease in the flow rate for a specific power setting on the pump. Attempts are continuing to try to remove any oxide contamination by charging relatively clean potassium and heating it in the loop to dissolve any oxides that may have formed. It is then drained hot and cooled to 200°F in the supply tank where hopefully the oxides will precipitate out. If difficulties persist it will be necessary to incorporate either a pump with a larger cross-section at the pumping section or an in line hot trap and a filter which will eliminate the accumulation of oxide at the pumping section.

The experience obtained with the equipment during the past two months has been extremely valuable, and the personnel now has a much better feel for its capabilities and operating characteristics. All instrumentation appears to be functioning properly, as do all of the components in the primary potassium circuit. The radiation attenuation apparatus for void fraction measurements has been assembled and the gamma source has been received. Alignment of the apparatus will occur in the very near future; in the meantime efforts are still under way

to obtain an independent calibration of the method on an air-water system. These procedures are more fully described in this and preceding reports.

- Agravic studies have progressed to the assembly stage during this quarter. Operation should be forthcoming during the next quarter with results available for dissemination in the final report at the end of the summer.

Progress on all phases of the contract is expected to accelerate during the months of June, July, and August, when personnel will be available for full-time activity. Many of the difficulties, which are inevitable in this type of research, have retarded progress to date. Experience accumulated to date should minimize delays in dealing with future problems. Once the startup difficulties are remedied the experimental programs have been planned to yield a maximum of data in as short a time period as possible. Data reduction procedures will be initiated and pre-tested in an effort to minimize the time required for analysis subsequent to obtaining the necessary data. Barring further serious difficulties, this should enable project personnel to produce a final report on all phases in September.

## POOL BOILING STUDIES

C. Phillip Colver

### A. Experimental Program

During the latter part of March the boiling chamber was fitted with a boiling tube of the design as described in the Fourth Quarterly Report, the vessel charged with potassium, and ten successful runs performed. The determination of three burnout points were included in these runs, two at subatmospheric pressures and the third at one atmosphere. The subatmospheric burnout points were determined by holding the heat flux constant and slowly and continuously decreasing the pressure until incipient burnout was reached. The atmospheric burnout point was inadvertently reached in the tenth run and was reached by maintaining the pressure essentially constant and increasing the heat flux in steps. When burnout was reached, it was not possible to shut off the power supply before complete tube failure occurred. The power to the tube at burnout was not accurately read, thus a reliable value of heat flux for this point was not obtained. Removal of the tube showed that it had completely melted at its midpoint. Only the half attached to the wall could be recovered for examination. The condition of the other half, subsequent to burnout, is unknown. Because of this inability to prevent catastrophic failure in this third burnout nearly all subsequent burnout measurements were made by holding the flux constant while decreasing the system pressure.

A second boiling tube was installed and a series of successful runs made. Four additional burnout points were obtained from 1 to 14 psia. Four runs were also made to determine the boiling curve in nucleate boiling regime. The tube was then removed from the apparatus and inspected to see what effect prolonged high flux boiling and

incipient burnout would have on the heat transfer surface. The tube appeared as it did initially with no noticeable surface changes except the end of each brazed thermocouple groove beyond the thermocouple well. A slight amount of microbrazing in the last 3/16-in of each groove was eaten away giving the appearance that there may have been erosion or dissolution of the braze at these locations. Fortunately, the thermocouple in each well was far enough removed for these indentations that the thermocouple readings should not have been affected significantly.

A third boiling tube was recently installed in the apparatus and further boiling runs performed. Five additional burnout runs were obtained in the pressure range 0.7 to 22 psia. Nucleate boiling data was determined from subatmospheric pressures up to approximately 45 psia. In each nucleate boiling run an attempt was made to obtain data near the Burnout point without actually reaching it. In two runs the burnout point was inadvertently reached, however, the stepped increases in flux were gradual enough so that the power source could be cut off before actual tube failure occurred. Obtaining two burnout determinations by this technique had the fortuitous result that a definitive check could be made for the reproductibility of determining burnout by the two techniques.

The raw burnout data has been reduced and preliminary values for the eleven burnout points are shown in Figure 1. The plot shows the heat flux at burnout as a function of the saturation pressure. It is seen that the two burnout points determined by heat flux increases compare favorably with those found at constant flux by decreasing the system pressure.

A comparison of the data is made with correlations of Noyes,<sup>(1)</sup> Zuber and Tribus,<sup>(2)</sup> Rohsenow and Griffith,<sup>(3)</sup> and Kutateladze.<sup>(4)</sup>

A computer program has been written for the IBM 7090 and is presently being used to correlate the nucleate boiling data. The program utilizes a least-square subroutine to determine the best-fit relationships for the boiling curve. In addition, deviation errors from the actual data, percent deviation, and standard deviations are determined for each run. The processing of this data is incomplete and is not presented at this time.

#### B. Heat Flux Error and the Temperature Profile in the Boiling Tube

It might be expected that end effects in the boiling tube are of importance inasmuch as the L/D ratio of tube is 3. A preliminary value for the total end heat loss at a flux of  $1 \times 10^6$  Btu/(hr)(sq ft) was reported in the last quarterly and estimated to be 15% of the total power dissipated in the tube. The method for calculating such losses has been refined somewhat by formulating the differential equation for heat transfer from a cylinder with internal generation. Several simplifying assumptions have been employed to permit an analytical solution. Adverse boundary conditions were set to obtain an estimate of the maximum losses. The losses at the two ends were considered to be approximately equal and therefore the longitudinal temperature profile was considered to be symmetrical about the midpoint of the tube. The boundary conditions reflect this assumption and the analysis applies only to half of the tube,  $X = 0$  to  $X = l/2$ , where  $X = 0$  corresponds to the midpoint and  $l$  to the total length of the tube extending into the potassium pool.

The differential equation is formulated for the graphite rod. The equation includes a term for the radial surface heat transfer and was

formulated using an overall coefficient,  $U$  which includes all interfacial and material resistances. The BN, Haynes-25, and interfacial resistances are contributors. The boundary condition at the end of the tube involves only the Haynes-25 disk and the film resistance.

Symmetry results in no transfer across the plane  $x = 0$  (see Figure 2).

It should be pointed out that at  $x = -l/2$  (the end of the graphite which contacts the molybdenum) a considerably different condition exists. However, since  $I^2R$  dissipation in the molybdenum will tend to reduce the magnitude of the graphite end losses it was felt the largest loss would likely occur at the free end of the tube. Thus, the analysis described applies to that end. Again the  $I^2R$  dissipation in the Haynes disk is neglected so that the actual loss would be somewhat less than that predicted here.

The general one-dimensional problem is given in Carslaw and Jaeger.<sup>(5)</sup> For specific boundary conditions, Lyons<sup>(6)</sup> solved the problem and determined errors in calculating the radial heat flux near the center of a Globar heating element. The present problem assumes no radial temperature gradients in the graphite (one-dimensional) and that all physical properties are constant with temperature.

The differential equation is:

$$\frac{d^2T}{dx^2} - \frac{4UT}{k_g d} = - \frac{cI^2R}{k_g V} \quad (1)$$

where  $T$  = (temperature in the graphite) - (temperature of boiling potassium)

$x$  = length dimension,  $0 < x < l/2$

$k_g$  = thermal conductivity of graphite

$U$  = overall heat transfer coefficient between graphite and boiling potassium

$I$  = current

$R$  = resistance of graphite

$V$  =  $1/2$  volume of graphite

c = conversion factor from watts to Btu/hr

The boundary conditions for the graphite rod heater are:

$$\frac{dT}{dx} = 0 \quad x = 0 \text{ (center of tube)} \quad (2)$$

$$\frac{dT}{dx} = \frac{-k_{H-25} T}{k_g t} \quad x = l/2 \text{ (free end of tube)} \quad (3)$$

where  $k_{H-25}$  = thermal conductivity of Haynes-25

$l$  = total length of graphite

$t$  = thickness of Haynes-25 tube end

The first boundary condition assumes equal heat transfer out each end of the graphite heater while the second condition is a heat balance at the interface between the graphite and the end of the Haynes-25 bayonet tube. Applying the two boundary conditions gives the following particular solution:

$$T = \frac{B/A^2}{\frac{k_g t A}{k_{H-25}} \sinh \frac{Al}{2} - \cosh \frac{Al}{2}} \cosh \frac{Al}{2} + \frac{B}{A^2} \quad (4)$$

in the region  $0 < x < l/2$  and where  $A^2 = 4U/k_g d$  and  $B = cI^2 R/k_g V$ .

This expression represents the temperature along the graphite heater and can be used to determine the heat loss out either end or the radial heat flux at any point along the boiling tube.

Using for the thermal conductivity of the graphite,  $k_g = 20 \text{ Btu/(hr)(sq ft)(°F/ft)}$ , the thermal conductivity of Haynes-25,  $k_{H-25} = 20 \text{ Btu/(hr)(sq ft)(°F/ft)}$ , the diameter of the graphite heater,  $d = 0.23\text{-in}$ , and the total length of the graphite heater,  $l = 1.25\text{-in}$ , gives:

$$T = \frac{545 \frac{I^2 R}{U}}{t \sqrt{10.4 U} \sinh\left(\frac{\sqrt{10.4 U} l}{24}\right) - \cosh\left(\frac{\sqrt{10.4 U} l}{24}\right)} - \frac{545 I^2 R}{U} \quad (5)$$

for  $0 < x < 1.25/24$ -ft.

To obtain the most adverse value for heat loss, the first term on the right hand side should be a maximum. This is accomplished by setting the thickness of the Haynes-25 end to zero or  $t = 0$ , then

$$T = \frac{545 I^2 R}{u} - \frac{545 \frac{I^2 R}{u} \cosh(\sqrt{10.4 u} x)}{\cosh\left(\frac{\sqrt{10.4 u} 1.25}{24}\right)} \quad (6)$$

and

$$U_T = 545 I^2 R - \frac{545 I^2 R}{\cosh\left(\frac{\sqrt{10.4 u} 1.25}{24}\right)} \cosh(\sqrt{10.4 u} x) \quad (7)$$

This expression is equivalent to

$$\left[ \begin{array}{c} \text{radial heat transfer} \\ \text{from boiling surface} \end{array} \right] = \left[ \begin{array}{c} \text{total heat} \\ \text{input} \end{array} \right] - \left[ \begin{array}{c} \text{end loss} \end{array} \right] \quad (8)$$

The heat flux error at the center of the tube, where the thermocouples are embedded, is given by the following expression:

$$\text{Percent error} = \left[ \frac{\frac{545 I^2 R \cosh(\sqrt{10.4 u} x)}{\cosh\left(\frac{\sqrt{10.4 u} 1.25}{24}\right)}}{545 I^2 R} \right] \quad (9)$$

Choosing the total heat transfer coefficients for the graphite-boron nitride contact and boron nitride-Haynes-25 contact,  $h(\text{contacts}) = 2000 \text{ Btu}/(\text{hr})(\text{sq ft})$ , the boiling heat transfer coefficient,  $h(\text{boiling}) = 10,000 \text{ Btu}/(\text{hr})(\text{sq ft})$  and finally the thermal conductivity of the boron nitride sleeve  $k(\text{BN}) = 15 \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F}/\text{ft})$ , the overall heat transfer coefficient is calculated to be  $U \approx 750 \text{ Btu}/(\text{hr})(\text{sq ft})$ , and the heat flux error at the center of the tube is then:

$$\text{Percent error} = \left[ \frac{100}{\cosh\left(\frac{\sqrt{10.4 (750)} 1.25}{24}\right)} \right]_{x=0} = 2\% \quad (10)$$

The average heat flux over the middle half of the boiling tube is determined from the following equation:

$$q/A_{ave} = \frac{\int_0^{L/4} (q/A)_x dx}{L/4 - 0} \quad (11)$$

The value for the heat flux is given by Equation 7.

$$q/A_{ave} = \frac{\int_0^{1.25} [545 I^2 R - 545 I^2 R \frac{\cosh(\sqrt{1044} x)}{\cosh(\sqrt{1044} 1.25)}] dx}{1.25 / 4(12)} \quad (12)$$

for  $U = 750$

$$q/A_{ave} = 545 I^2 R [1 - 0.0432] = 545 I^2 R (0.957) \quad (13)$$

Since the term  $545 I^2 R$  represents the theoretical radial heat flux from the graphite rod, the average flux over the middle half of the tube is then 95.68% of this theoretical value.

The temperature profiles in the graphite at heat fluxes of  $1 \times 10^6$ ,  $5 \times 10^5$ , and  $1 \times 10^5$  Btu/(hr)(sq ft) are shown in Figure 2. The heat flux at any point along the graphite rod is determined by simply multiplying the temperature by 750.

#### FILM BOILING

Andrew Padilla, Jr.

The film boiling apparatus was operated with water as the fluid in both compartments to obtain operating experience and to predetermine the significance of edge effects. However, operation was severely limited because of the undesirability of heating the Cb-1 Zr over 400°F while in contact with water.

Nucleate boiling data with water at 1 atm was obtained. Boiling at reduced pressures was also carried out in an attempt to lower the critical heat flux, but overloading of the condenser prevented operation in the film boiling regime. Another technique tried was to heat the

boiling plate with the upper chamber empty and then slowly introduce fluid above the boiling plate. Due to the inadequate  $\Delta T$ , boiling in the transitional regime was obtained followed by a change to nucleate boiling with the addition of more water.

A tantalum heater was used in the initial runs on water. However, inadequate environmental control in the outer vessel resulted in catastrophic oxidation of the heater. An extensive check for leaks uncovered several sources of trouble. These difficulties are being corrected and a new heating element of a slightly different design installed. The micro-thermocouples to be used in the boiling plate have been calibrated and the lead wires attached. The radiation shields, guard heaters, insulation, and check thermocouples will be installed prior to retesting of the outer vessel and subsequent loading.

If a satisfactory atmosphere can be maintained in the outer vessel, sodium will be charged to the lower compartment and potassium to the upper chamber. Boiling runs will be initiated immediately.

#### FORCED CIRCULATION STUDIES

R. E. Barry

##### Status of the Forced Circulation Loop

On March 27, the loop was charged with potassium from the supply tank and circulation was begun under argon pressure at 800°F. All control systems functioned as desired.

However, after 3 hours of circulation at 1.6 GPM, the flow rate began to drop off in a manner suggesting plugging and finally ceased altogether in another 2 hours. During the next two weeks efforts were made to dislodge the plug by the application of heat and pressure. These methods failed and it was necessary to drain the loop and remove the pump.

The pumping section (1/16-in by 3/8-in) was almost solidly plugged and was cleaned by alternately rodding and flushing with methanol and methanol-water mixtures.

Commercial grade potassium containing about 2% sodium had been provided with the loop. It is believed that the sodium present in the potassium was selectively oxidized and precipitated. Plots in the Liquid Metals Handbook show that the solubility of sodium oxide in potassium is substantially lower than that of potassium oxide. There is some question as to the source of the oxygen. A mass spectrometer test run on the argon used for cover gas indicated 150 ppm oxygen (higher than the 4 ppm specifications). However, all the argon used since startup would have formed only about 0.1 cc of sodium oxide. It is reasonable to suspect, however, that contamination of the argon was a contributory factor and, therefore, an inert gas purification system (a NaK bubbler) has been placed on the inert gas line.

In late April and early May we took the following action in an effort to remove as much of the oxides from the system as possible:

1. Heated the system to 500°F and drained it to a shipping container.
2. Charged a higher grade potassium (less than 200 ppm Na, less than 800 ppm O<sub>2</sub>) through the cold trap, thus avoiding contamination with oxides deposited in the supply tank.
3. Heated the system to 1000°F to dissolve oxides in the loop itself.
4. Drained the system through the supply tank to a shipping container, thus flushing the system completely. The temperatures throughout were maintained at as high a level as was feasible to keep oxides in solution.

5. Welded the pump in place.
6. Again charged the higher purity potassium, heated the loop to 1000°F to maintain the oxides in solution and circulated for 4 hours.
7. Dumped the loop hot into the supply tank.
8. Again charged high purity potassium through the cold trap and attempted to operate. During this operation, both line heaters in the subcooler burned out. A one-week shutdown was necessitated while some cone heaters were prepared and installed.

The above procedure was followed to remove as much oxide as possible from the inside surfaces of the loop and precipitate them in the supply tank which is held at 200°F.

On May 14, circulation was resumed at 1.3 GPM and 740°F and the potassium was gradually heated to 900°F. After 6 hours of operation, the flow had dropped to 0.6 GPM. Operation was terminated at this point.

Apparently, oxides still were present in the loop and were collecting in the restricted pumping section. The loop was drained hot into the supply tank. The potassium was then cooled to 200°F. The loop was recharged at 200°F, heated to 600°F and circulation was again attempted. The flow rate was still low and the loop was drained.

An analysis of the situation concluded that there are still oxides on the internal surfaces of the loop. The preheaters and hotwell with the largest surfaces are probably the main cause of trouble. The procedure now being followed is outlined below. (Refer to Figure 3.)

1. With the throttle valve closed, charge the preheaters with 200°F potassium from the supply tank.
2. Freeze the potassium in the flowmeter.
3. Open the throttle valve and charge potassium from the supply tank through the pump to fill the hotwell.

4. Heat the preheater and hotwell to 1000°F.
5. Drain the hotwell through the level line into the supply tank.
6. Drain the subcooler and pump into the supply tank.
7. Shut the throttle valve.
8. Melt the potassium in the flowmeter and drain the preheaters into the supply tank.
9. Cool the supply tank to 200°F.
10. Repeat steps 1-9 twice (we have completed one cycle at this writing).

Having cleaned the loop surfaces, an attempt to dissolve the plug in the pump will consist of the following steps:

1. With the throttle valve closed, charge the preheaters with 200°F potassium.
2. Heat the preheater to 1000°F.
3. Open the throttle valve and allow 1000°F potassium to flow by gravity backwards through the pump. This is expected to completely free the pump. A small amount of power may be applied to the pump with the leads reversed to help maintain local temperatures above those elsewhere in the loop.
4. Drain the loop.
5. Cool the supply tank to 200°F.

The above procedure will be repeated until normal circulation is obtained. If the above procedures do not succeed several courses of action are being considered. The first would involve replacing the pump with a second one having a larger pumping section. This would likely result in a head loss, but it should permit sufficient circulating time to clean up the system sufficiently so that oxide concentration can be controlled with the cold trap.

The second possibility consists of installing an in line hot trap to control oxygen concentration. Serious consideration is being given to this possibility.

A third possibility involves inserting a packed section upstream of the pump either in line or as a bypass to collect preferentially any oxide or crud which would otherwise lodge in the pump. A combination of possibilities 2 and 3 also possesses considerable merit.

These procedures and considerations will occupy personnel through June. It is hoped that startup difficulties will be clarified by July and the program initiated.

#### TWO-PHASE FLOW STUDIES

Lowell R. Smith

The equipment for calibrating the gamma ray attenuation method,-- i.e., for investigating the functional nature of the attenuation in a flowing air-water system,--is currently being constructed. This apparatus is essentially that shown in Figure 12 of the Fourth Quarterly Progress Report. The 1-ft long stainless steel test section has been fitted into the quick-closing valves. Fabrication has been accomplished such that the tube fits against the valve seat, thus minimizing discontinuities in the flow channel. The air bleed fittings have been attached to the test section just inside the snap valves. The balance of the construction is considerably simpler, and it is hoped to be able to start check runs in the near future.

All components of the gamma ray attenuation apparatus, for obtaining void fraction data on the test loop, are ready for use. As soon as the loop is operating smoothly the detection equipment will be connected and background counting will commence. Then data will be obtained, as permitted by the loop.

Two computer programs are now ready for comparison with the forthcoming two-phase pressure drop data. The Lockhart-Martinelli method program has been successfully operating for a year. Recently, a program based on the two-phase  $f$ -factor method of Bertuzzi, Tek and Poettmann<sup>(7)</sup> has been prepared. These two programs give substantially the same results, as is illustrated in Figure 4, for two-phase potassium flow at 1600°F. The  $f$ -factor program, as it currently exists, is valid up to qualities of 0.5 and for liquid phase Reynolds numbers (based on total pipe cross-section) greater than 10,000. It is evident that the  $f$ -factor method predicts drops somewhat higher than does the Lockhart-Martinelli method. It will be interesting to see which method best fits the experimental data.

#### LIQUID METAL BOILING IN AGRAVIC FIELDS

Herman Merte

All of the test vessel components have been received with the exception of the outer pressure vessel. On assembling the two halves of the vessel, the buttress threads siezed due to erratic galling of the stainless steel, even with lubrication. It is believed that a thin plating of hard chrome will relieve this condition, and this is presently being done.

The stainless steel foil has been attached to the main copper heater cylinder in the same manner as previously described. The surface has a more coarse appearance than the earlier sample, but still appears to be acceptable. Profile measurements will be made if this can be accomplished without marring the surface.

Calibration of the thermocouples has been delayed due to prior use of the calibration apparatus by other personnel in the laboratory. Figure 5 shows a representative thermocouple circuit necessary to

bring the my readings from the pressure vessel while under rotation. The measuring junction and reference junction materials are cut from the same piece of material as furnished by the manufacturer. It was originally planned that the extension wire would be that used to make the particular thermocouple. However, the gage of wire used in constructing the swaged assembly was too large to make this practical. With extension wire of perhaps slightly different thermoelectric characteristics it will be necessary to insure that the temperatures at junctions  $T_1$  and  $T_2$  (Figure 5) are as close to each other as possible. Tests will be conducted on each thermocouple to determine the magnitude of any errors introduced due to differences in  $T_1$  and  $T_2$ . The transition to pure iron wires is necessary to avoid possible attack of the constantan by the mercury in the slip rings, but both the rotating and stationary junctions are immersed in the same liquid bath and the EMF's are cancelled. The connection of the measuring junction to the extension wire is made external to the pressure vessel, with the encased wires passing through a multiple hole pressure fitting.

Because of the complexity involved in assembling the test vessel, it is desirable that subsequent disassembly be kept at a minimum. One of the test variables is the depth of mercury in the inner test chamber, which will be adjusted to maintain the same hydrostatic pressure at the heating surface for the various g's. Mercury can be added and withdrawn through the vent tube without disassembly, but for data reduction purposes it is necessary that liquid depth be determined accurately. Careful metering of amounts added and withdrawn is one means of accomplishing this, and will be used. An independent direct method of measurement is incorporated and shown in Figure 6, utilizing the variation in resistance of a 30 gage pure iron wire with immersion depth.

One junction is made through the mercury and casing, and the other through a 20 gage tungsten wire insulated with quartz in passing through a compression fitting in the inner test chamber cover. The wire is held in the mercury with the quartz extension rod as shown. No room is available in the outer pressure vessel cover for the additional electrical connection required. Since liquid depth measurements under non-operating conditions would be sufficient, access to the electrical lead will be made by removing the test vessel pressurizing line.

Figure 7 schematically shows the test vessel with some of the accessory equipment and modifications being made to the existing centrifuge. The test vessel is pivoted on one end of the cross arm, thus maintaining the acceleration vector perpendicular to the heating surface at all g's. The mass and center of gravity of the counterweight are adjustable and will correspond to those values for the test vessel in order that dynamic balance will exist at all rotational speeds.

Construction of the double fluid shaft seal at the upper end of the vertical shaft has been completed. This will furnish both a condenser coolant supply and argon supply of up to 300 psi for test vessel pressurization. An argon atmosphere is used to minimize oxidation of exposed copper surfaces in the vicinity of the heater. Prior to each test, the vessel would be evacuated and purged several times with argon. A high pressure flexible hose will connect the argon supply to the pivoting pressure vessel.

An adjustable electrical pressure switch is shown mounted in its approximate position on the pressure vessel in Figure 7. It is in the inner vessel vent line and is intended to cut off all power should the pressure exceed the particular operating pressure by a small amount.

In order to assure that the condenser coolant supply will completely fill the coils, a rotating seal and flow control valve were added to the lower end of the vertical shaft.

Assembly of the components will continue during the next period.

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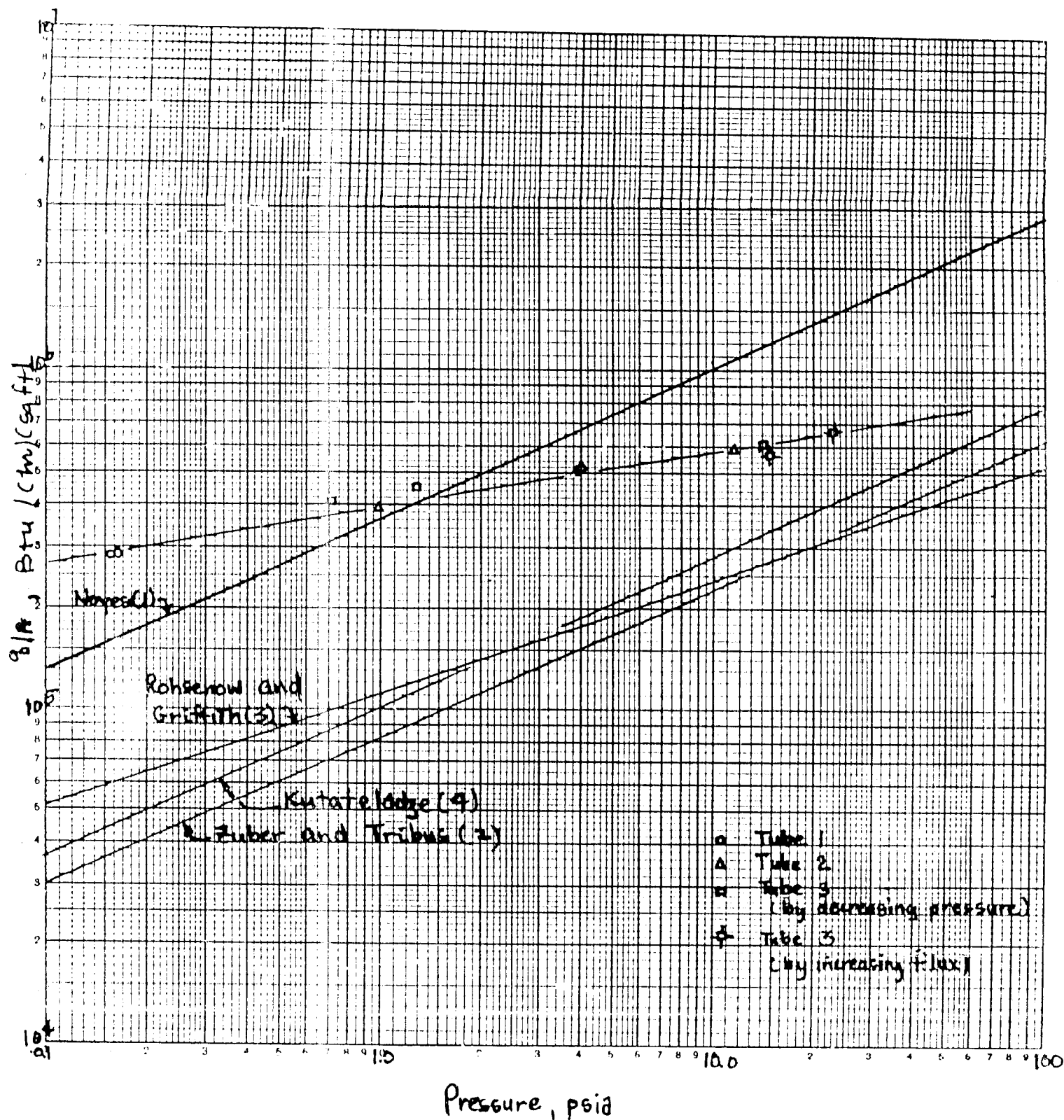


Figure 1, Burnout Heat Flux Versus Saturation Pressure for Saturated Pool Boiling Potassium.

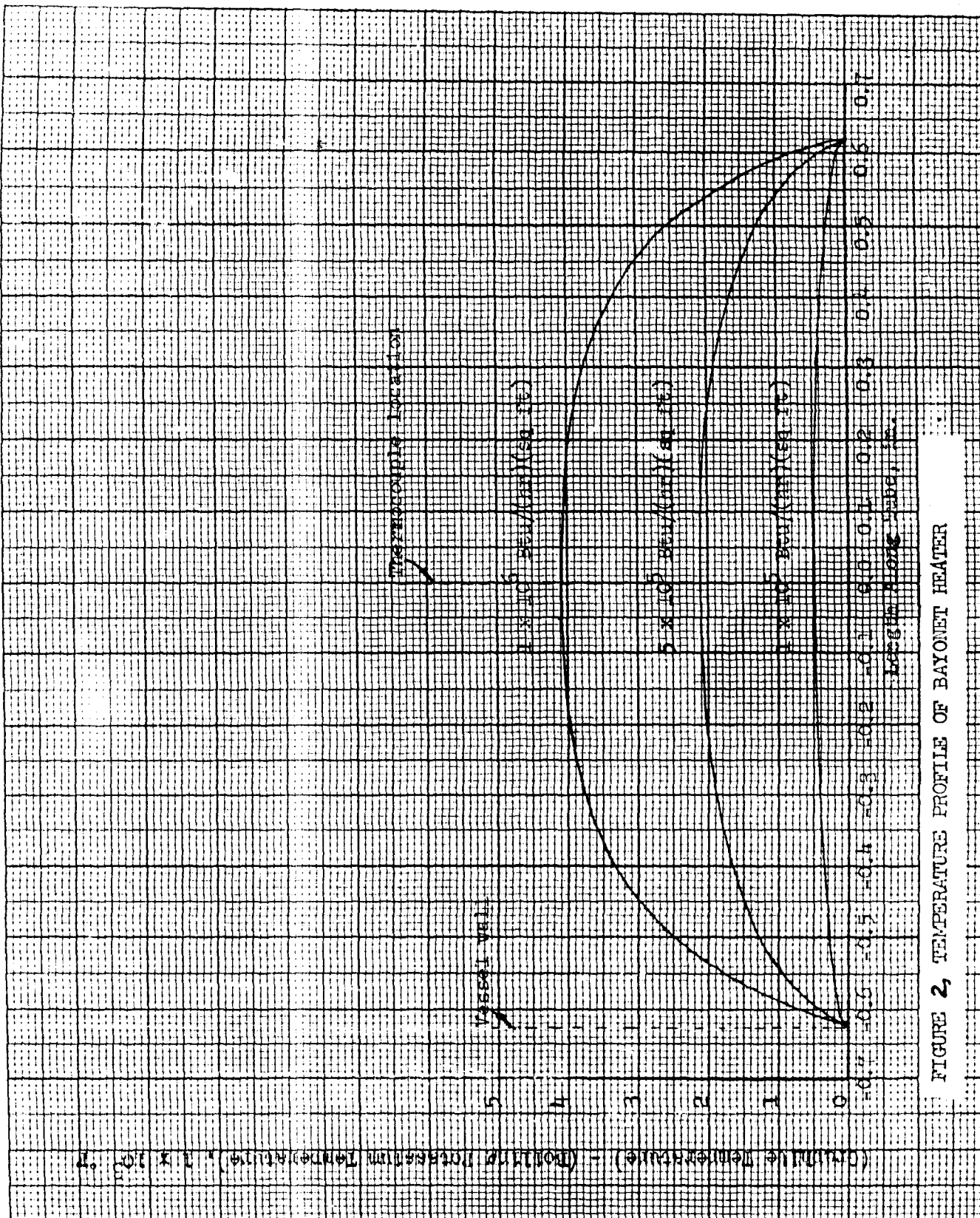


FIGURE 2, TEMPERATURE PROFILE OF BAYONET HEATER

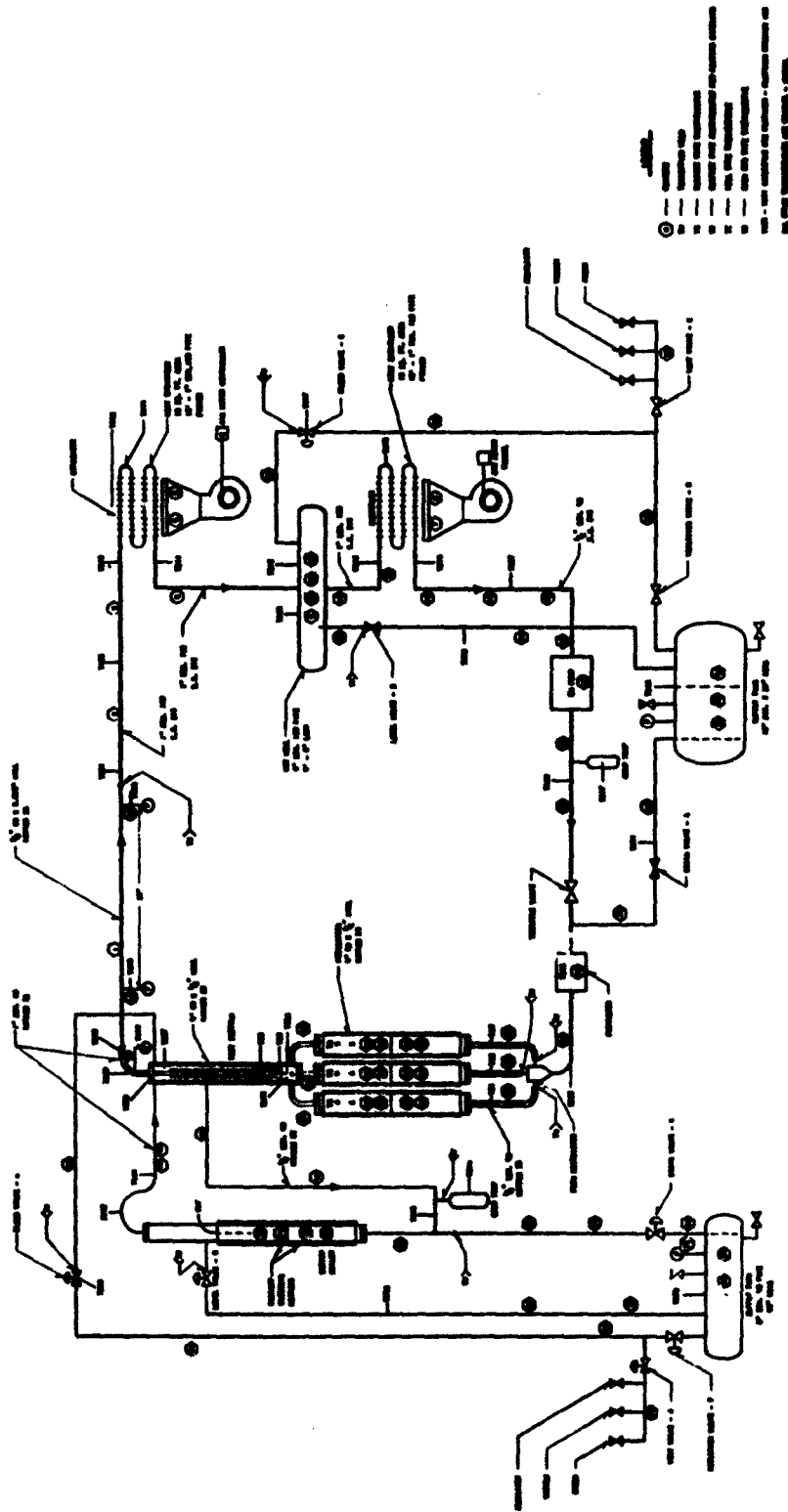
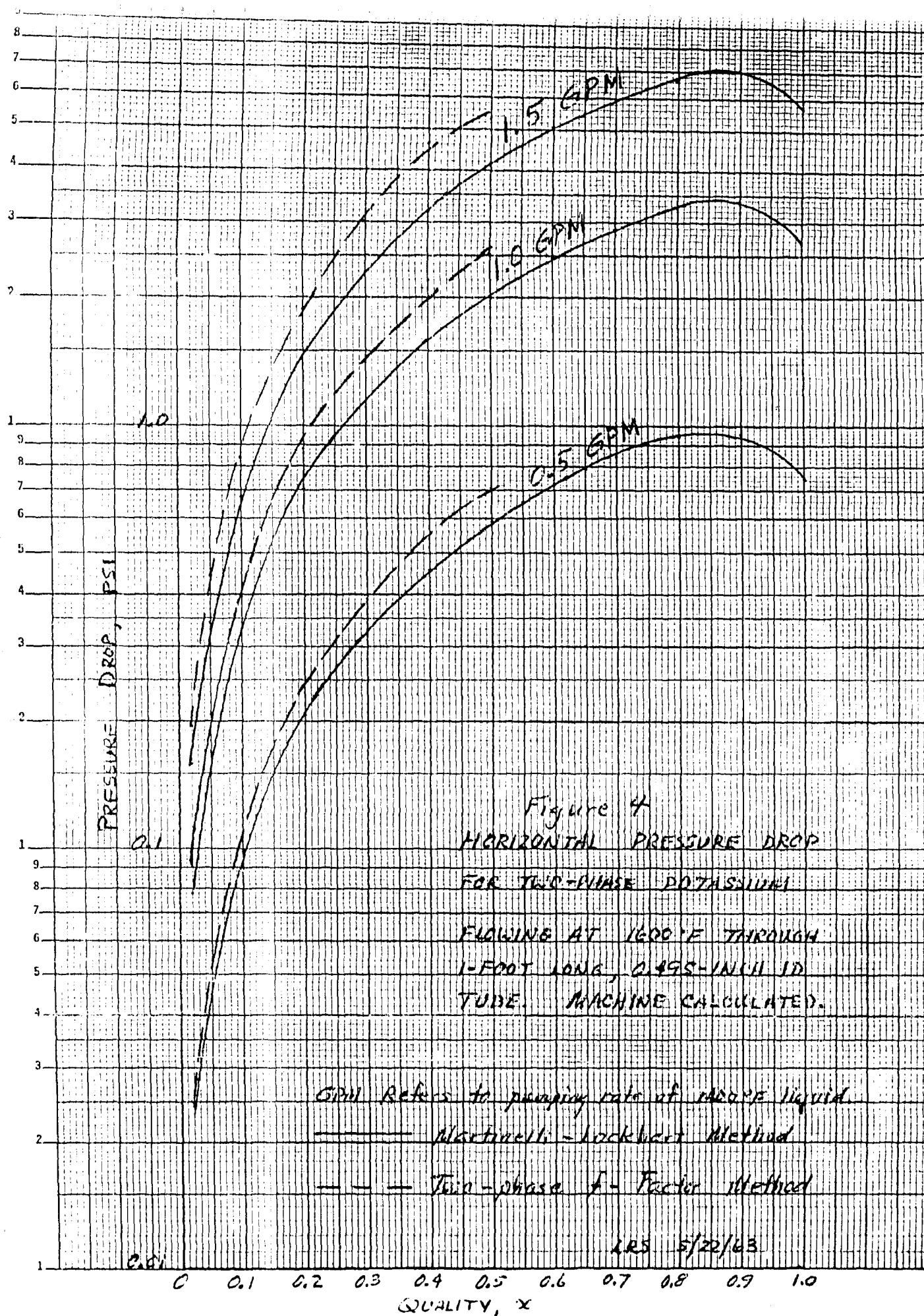


FIG. 3 - FLOW SCHEMATIC OF MICHIGAN BOILING LIQUID METAL LOOP

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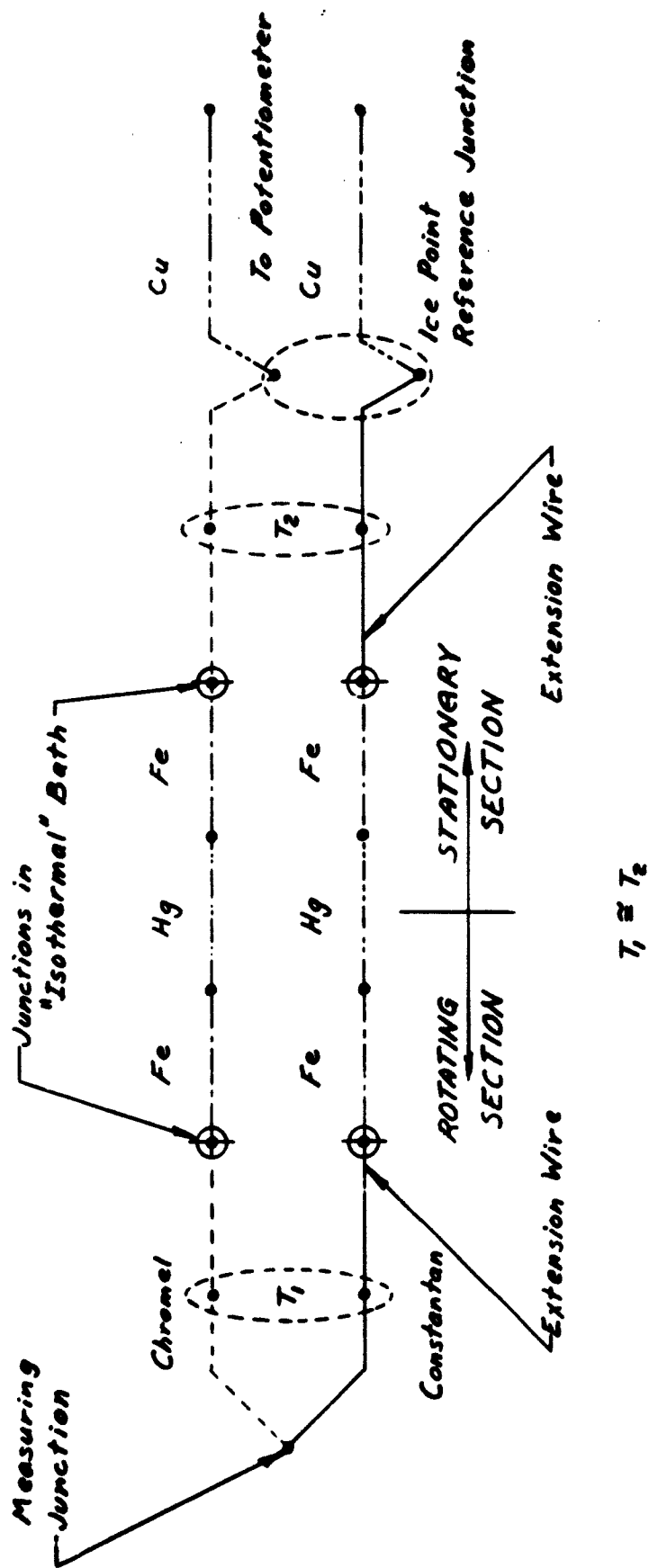


Figure 5 .Equivalent thermocouple circuit for temperature measurement with respect to ice point.

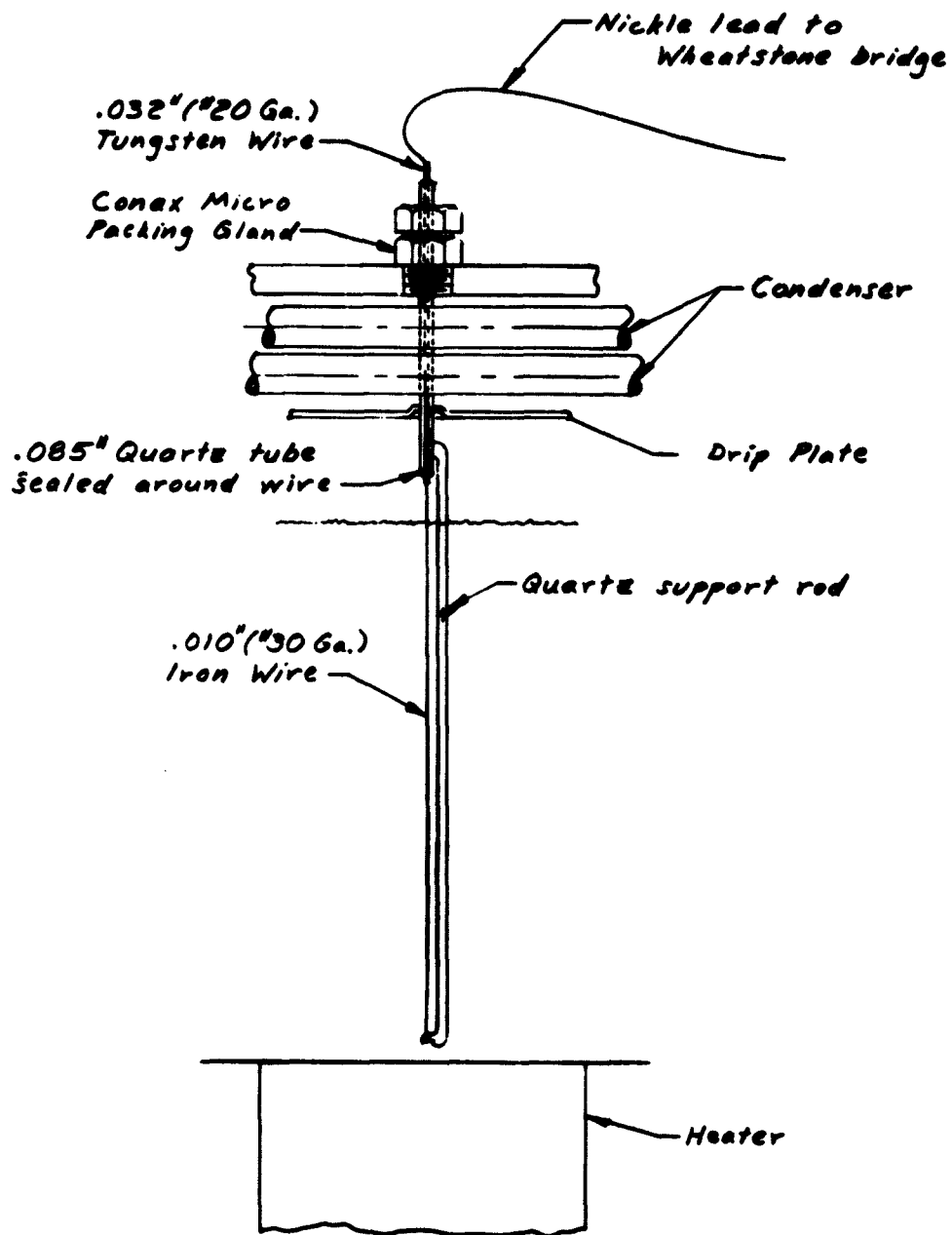
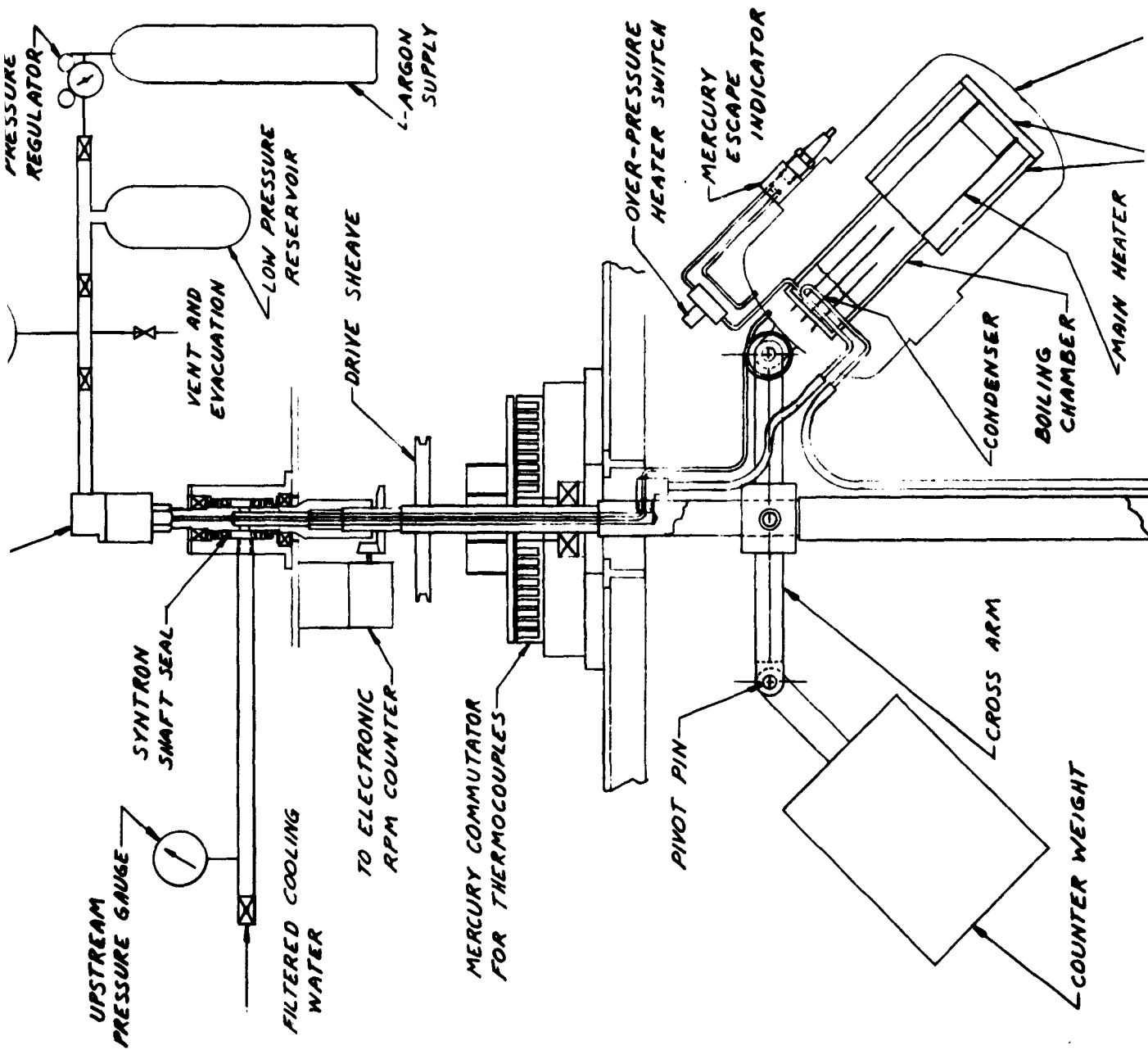
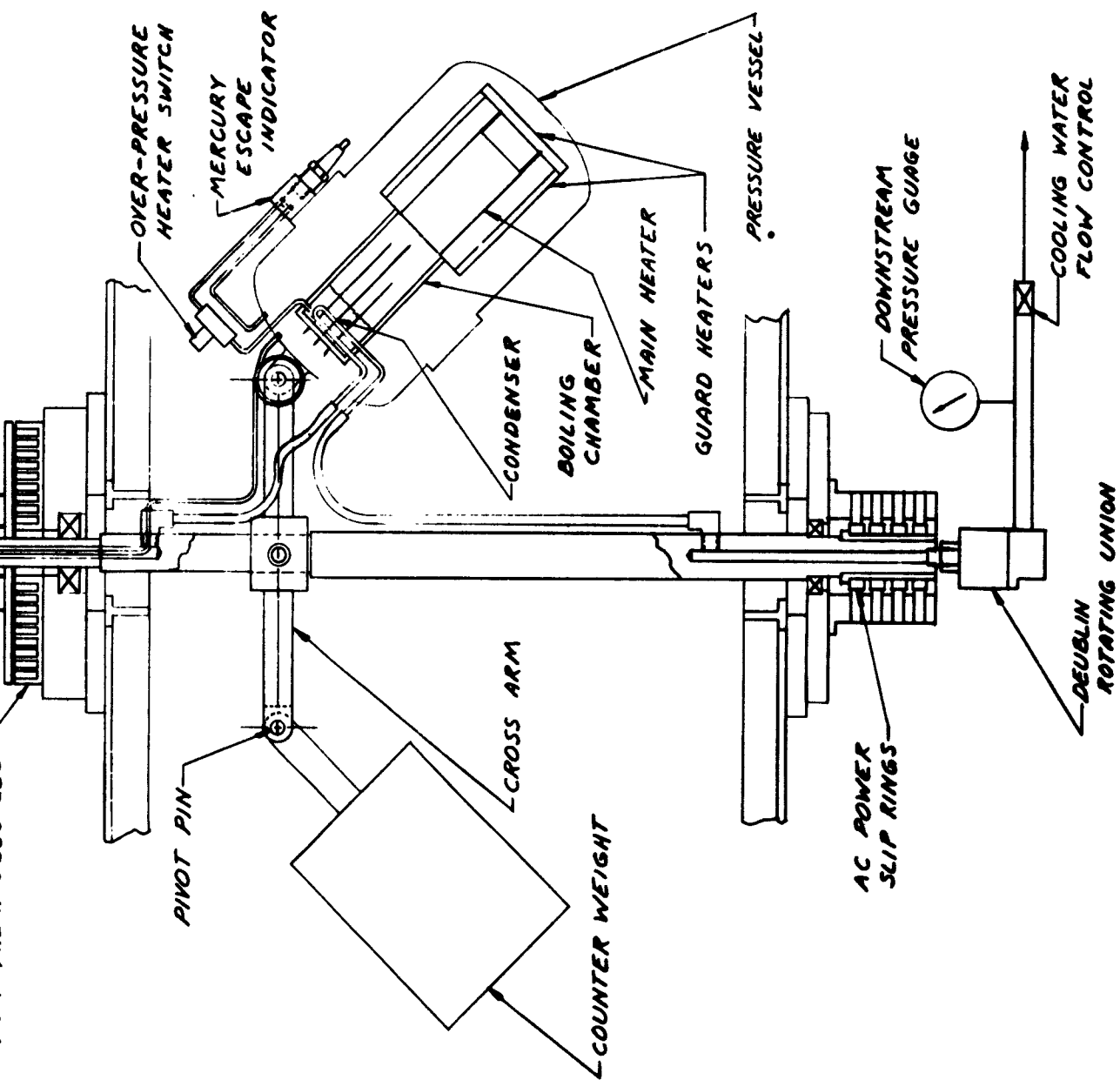


Figure 6 .Liquid level Indicator for mercury.





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FIGURE 7 . MERCURY BOILING TEST VESSEL IN CENTRIFUGE.